Bioastronautics Strategy

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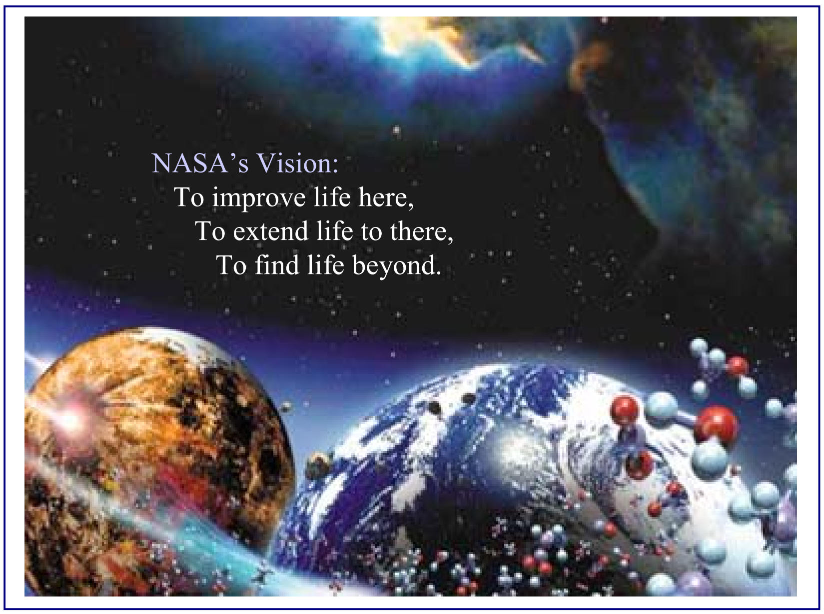
Bioastronautics Strategy

NASA Vision and Goals

Bioastronautics is a focused effort to enable human exploration of space through effective risk management solutions and innovative science and technology discoveries. It is NASA's vision to reach beyond the current boundaries of human space flight, to steadfastly ensure the safety, health, and productivity of its space crews, and to utilize the knowledge gained in such a quest to improve life on Earth.



Bioastronautics is instrumental in enabling the Agency to reach its vision and accomplish its goals. It provides major support for the Agency's goals, particularly enabling Goal 9, to *extend the duration and boundaries of human space flight to create new opportunities for exploration and discovery*. Bioastronautics supports the Agency's mission-driven Goal 4, to *explore the fundamental principles of physics, chemistry, and biology through research in the unique natural laboratory of space*. Attainment of those goals relies on a set of collaborative relations and partnerships both within NASA and with the scientific community, industry, other governmental and non-governmental agencies, and international programs.

This strategy, sponsored by the Office of Space Flight, the Office of Biological and Physical Research, and the Office of the Chief Health and Medical Officer, describes the mission and goals of Bioastronautics, the major assumptions, and the overall approach in support of the primary responsibility — successful risk management for the human subsystem of space flight. Realization of this strategy will provide the Agency and its stakeholders with highly developed risk management solutions for all mission scenarios including Space Shuttle, extended-duration habitation of the International Space Station, and future exploration missions. In addition, this pursuit will yield new opportunities for scientific discoveries and advanced technologies for understanding and overcoming the human limitations to the hazardous environment of space.

The Appendices provide additional pertinent information: Table A-1 illustrates how Bioastronautics fits with the Agency goals and objectives; Table A-2 lists Bioastronautics stakeholders, partners, customers, and advisors; Table A-3 presents the primary Bioastronautics organizations and their functions; Table A-4 provides details on the Bioastronautics Critical Path Roadmap (BCPR) risks.

Background

What is Bioastronautics?

Bioastronautics is the study of biological and medical effects of space flight[1] on human systems. It establishes tolerance limits to the extreme environments of space and develops efficient and effective countermeasure strategies to overcome those limitations. It spans the research, operational, and policy issues related to human space flight. NASA envisions an outcome-driven program, based on the Bioastronautics Critical Path Roadmap[2], that ensures the safety, health, and optimum performance of astronauts through the systematic identification, assessment, and management of critical risks associated with the human subsystem of space flight (other examples of subsystems include propulsion and life support).

The Foundation of Bioastronautics:

- **Considers the human as a critical subsystem of space flight**
- **Risk-based**
- **Focused on specific outcomes to ensure that the human is not the limiting factor for long duration spaceflight**
- **Enables informed decision making**
- **Provides highly developed risk management solutions**

Brief History of Bioastronautics

The 2001 Presidential budget established the Bioastronautics initiative. The purpose of the initiative was to develop a new approach for life sciences research that would focus activities and result in effective countermeasures and innovative technologies for human space flight. As a result, the Office of Biological and Physical Research, Code U, established a Bioastronautics Research Division with two functional elements, Advanced Human Support Technology and Biomedical Research and Countermeasures. The medical operations portion of Code U transitioned to the Office of Space Flight, Code M; the occupational health and medical policy functions were incorporated into the Office of the Chief Health and Medical Officer, Code AM. The Space and Life Sciences Directorate at the Johnson Space Center established the Bioastronautics Project Office with three functional components (space medicine and health care systems, habitability and environmental factors, and human adaptation and countermeasures). The Biological Systems Office in the Space and Life Sciences Directorate supports fundamental biology through its biotechnology and cellular sciences components.

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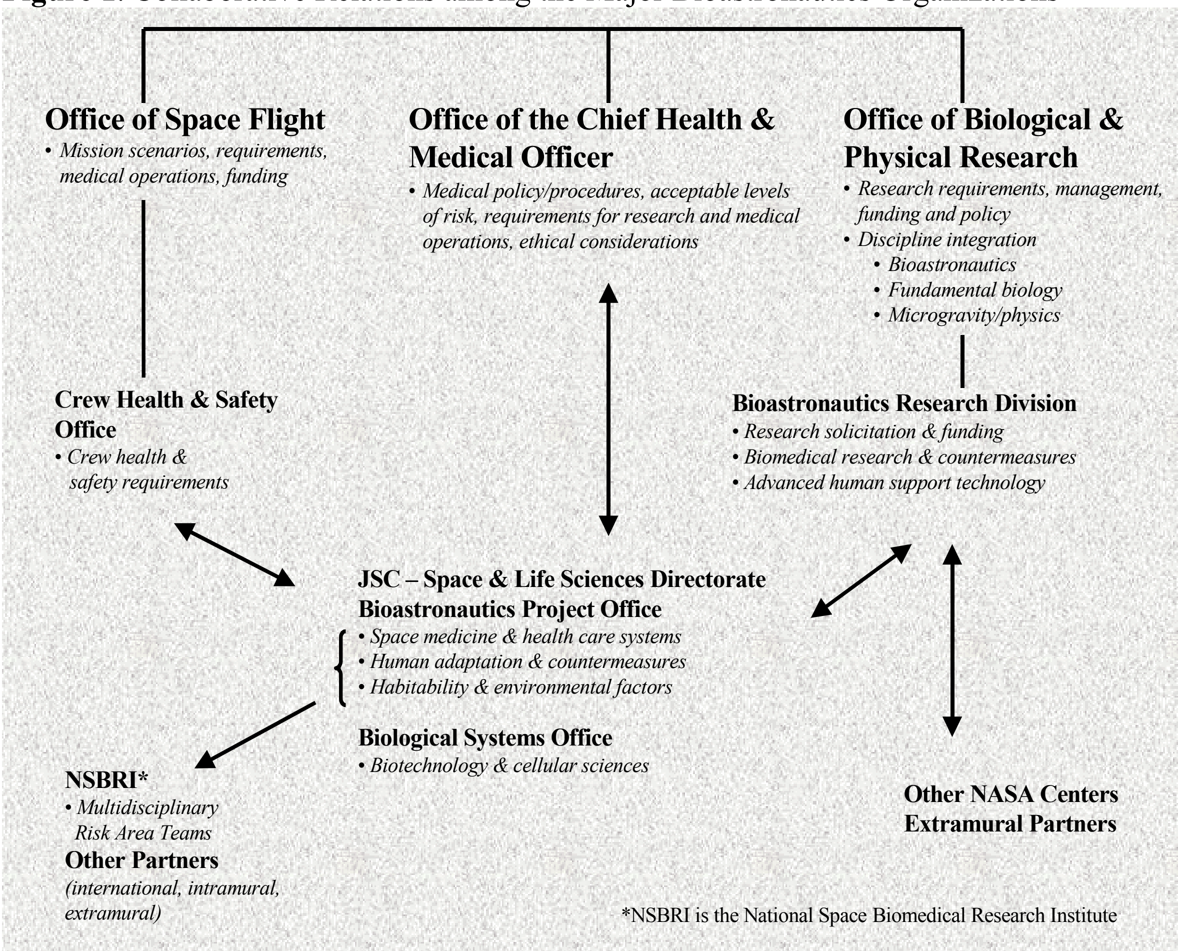
[1] The American Heritage Dictionary 2000 defines Bioastronautics as the study of the biological and medical effects of space flight on living organisms.

[2] The Bioastronautics Critical Path Roadmap (BCPR) aligns with recent recommendations of the NASA Research Maximization and Prioritization (ReMAP) Committee that endorsed the highest priority for Bioastronautics research areas for understanding and overcoming the limitations for human adaptation to space flight, including radiation health, behavior and performance, physiology, clinical/operational medicine, and advanced life support. The BCPR maps to the issues and recommendations contained in the reports of the major external advisory committees for Bioastronautics, including the National Academy of Sciences report of the Institute of Medicine, *"Safe Passage: Astronaut Care for Exploration Missions"* (2001); the two reports of the Space Studies Board Committee on Space Biology and Medicine, *"Review of NASA's Biomedical Research Program"* (2000) and *"A Strategy for Research in Space Biology and Medicine for the New Century"* (1998); and the National Research Council Committee on Advanced Technology for Human Support in Space report, *"Advanced Technology for Human Support in Space"* (1997).

These major organizations involved in the Bioastronautics effort and their collaborative relationships are depicted in Figure 1. As shown in the graphic, multiple organizations, at various

Figure 1. Collaborative Relations among the Major Bioastronautics Organizations



levels in the Agency, share responsibility for ensuring and improving crew health, safety, and performance. Collaboration across the major organizations is an essential, ongoing, and informal activity focused on the risk mitigation and management process for the human subsystem of space flight. Such collaboration has been the catalyst for this document (Codes AM, M, and U are the sponsors of the Bioastronautics Strategy) and continues to guide the risk management process including prioritization, funding, implementation, and communication of research and technology for ensuring crew health, safety, and performance. Additional information on the various organizations and their roles and functions, is contained in Table A-3 in the Appendix.

Bioastronautics Mission Statement:

- **Ensure the safety, health, and optimum performance of astronauts through the systematic identification and management of critical risks associated with the human subsystem of space travel**

Bioastronautics Mission Statement

The Bioastronautics mission statement reflects the Agency's commitment to the human aspects of space flight — the human is defined as a critical subsystem of space flight. As with any engineering system, tolerance limits and safe operating bands must be established for the human subsystem. Establishing tolerance limits includes setting mission-specific and lifetime health standards that protect astronauts from any adverse biomedical effects initiated by space flight during and after their flight career. Crews are certified for longer duration missions based on those limits.

The Bioastronautics risk-based approach allows for understanding and controlling the human health and performance risks, identifies specific outcomes, enables informed decision making, and provides the Agency with highly developed risk management solutions to meet its enabling and mission-driven goals and objectives. These goals and objectives foster a set of mission requirements that define the Bioastronautics risk management research and technology program, including the astronaut health care system.

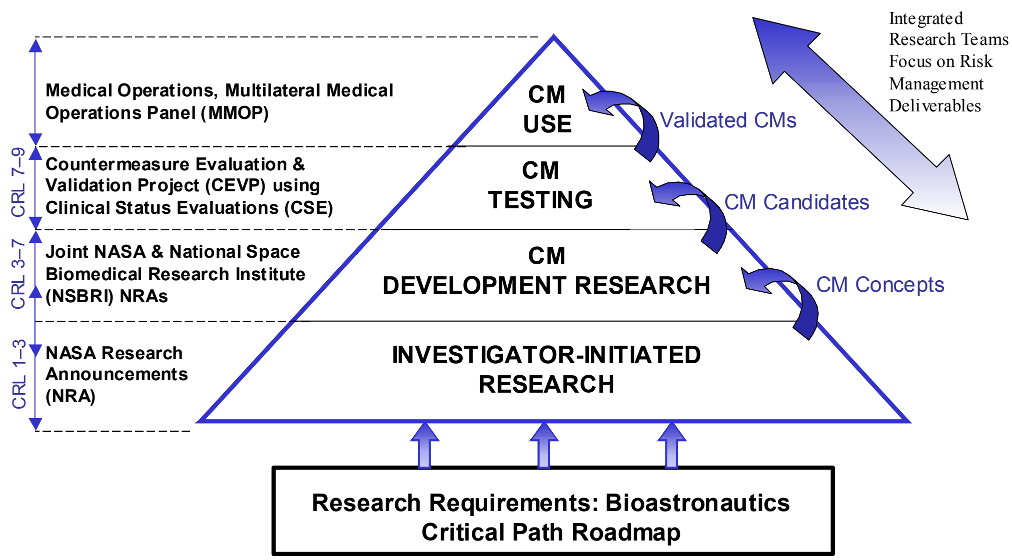
The crew health, safety, and performance requirements are defined at a top level (Table 1) and gain fidelity as mission specifications are further articulated (e.g., mission duration, fractional gravity environment, vehicle, tasks, communication, crew size, science questions). This in turn sets the stage for Bioastronautics risk management, which spans the identification and assessment of risks, risk prioritization, and resource allocation decisions, and ultimately, the selection of an optimal set of countermeasures and health care capabilities.

Table 1. Crew Health, Safety, and Performance Requirements

Manage the risk of adverse health or performance impacts to the crew or the mission from expected medical or psychological scenarios
Manage the risk of adverse health or performance impacts to the crew or mission from the environment (e.g., radiation, water, air, noise) and crew accommodations
Maintain the functional status of the crew to ensure their ability to meet all mission demands, including the postflight period (e.g., piloting, EVA, operational demands, emergency egress)
Follow a continuous improvement approach for existing systems, processes, equipment, and technology to maximize crew health, safety, and productivity (e.g., reduce crew time demands; reduce power, weight, cost)
Evaluate all biomedical research and space medicine deliverables for Earth-based applications

The development of countermeasures follows a pathway of maturation, or readiness levels, by which ideas and concepts emerging from basic research are developed into flight operations (Figure 2). The countermeasure development process begins with the identification of the biomedical issues and priorities identified through the BCPR (including review of advisory committee recommendations) and proceeds with participation by the extramural research community through focused research solicitations. This includes basic and applied research to test and validate hypotheses (Levels 1 – 3), formulation of countermeasure concepts and initial demonstration of efficacy (Levels 4 – 5), clinical trials/testing (Levels 6 – 7), and finally, validation and operational implementation (Levels 8 – 9).

Figure 2. Countermeasure (CM) Development Process



Bioastronautics Goals

To fulfill its primary role in the Agency's strategic plan for enabling Goal 9, *extend the duration and boundaries of human space flight to create new opportunities for exploration and discovery,* Bioastronautics has articulated three goals: manage risk; increase efficiency; and return benefits to Earth. Table A-1 in the Appendix shows the relationship between the Agency and Bioastronautics goals. These goals apply also to Agency mission-driven Goal 4*, explore the fundamental principles of physics, chemistry, and biology through research in the unique natural laboratory of space.*

Goal 1: Managing Risk

Risk management is achieved through the development of effective control strategies and can be measured at the level of individual risk, mission risk, or program risk. Risk management strategies are targeted to prevent the risk from occurring, or to intervene in the risk-consequence pathway in order to alter the likelihood of the risk's occurrence or the severity of its outcome — risk reduction. The goal for managing risk applies to all critical risks of the BCPR. These 55 risks are allocated across 12 disciplines and three functional components as shown below in Table 2 and further detailed in Table A-4 in the Appendix.

Table 2. Bioastronautics Functional Components and Discipline Areas

Functional Component	Discipline Area	No. of BCPR Risks*
Space medicine and health care systems	clinical capabilities	6
	multisystem alterations	1
Habitability and environmental factors	advanced life support	7
	food and nutrition	4
	environmental health and monitoring	3
	radiation effects	5
Human adaptation and countermeasures	bone loss	4
	cardiovascular alterations	5
	human behavior and performance	4
	immunology, infection, and hematology	6
	muscle alterations and atrophy	5
	neurovestibular adaptation	5

* Many of the BCPR risks, associated with a discipline area, have application to other disciplines or functional components

Goal 2: Increasing Efficiency

The goals for increasing efficiency include: increased resource availability during the mission (such as greater power, mass, volume, and crew time) and reduced costs (such as development time) through design solutions for the human subsystem elements; this is a crosscutting goal and requires the development of a systematic and continuous improvement process applied to all BCPR risks. Such an approach should be followed for existing systems, processes, equipment, and technology to maximize crew health, safety, and productivity for all mission scenarios.

Goal 3: Returning Benefits to Earth

Returning benefits to Earth, a crosscutting goal, focuses on increasing the value of space-based research to Earth-based applications. It requires the solicitation and funding of meritorious research and the development of systematic assessment and dissemination strategies for the important scientific findings. These strategies aim to acquire and disseminate knowledge and technology in clinical, operational, biomedical, environmental, and habitability areas that have application for improving the quality of life on Earth. All biomedical research and space medicine and health care system deliverables will be evaluated for such applicability.

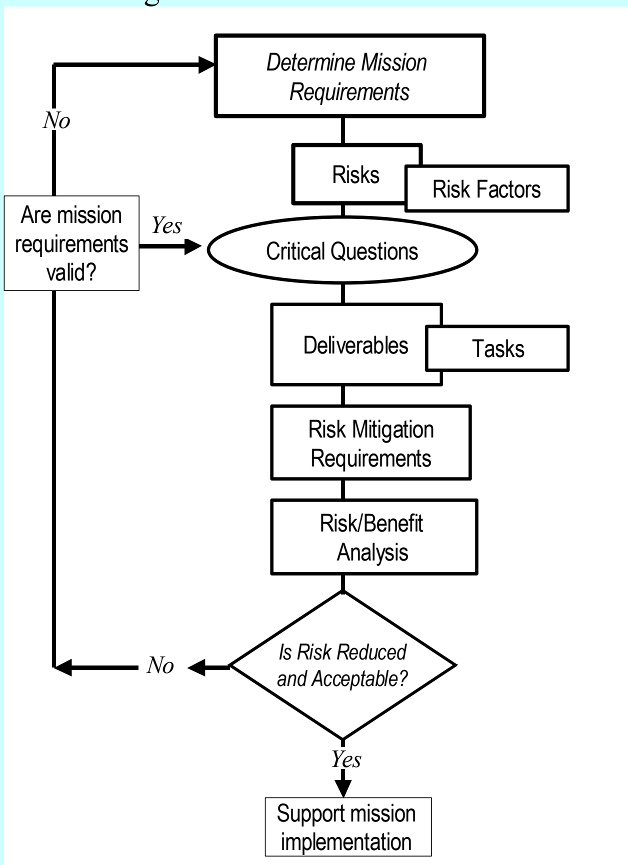
Bioastronautics Objectives

The objectives for Bioastronautics address the three goals above and encompass the risk management process. The risk management process (Figure 3), based on the Bioastronautics

Critical Path Roadmap, is comprised of the four components described below. Further specification of the objectives and performance metrics are contained in the Bioastronautics Tactical Plan.

Managing Risk Objectives

Figure 3. Bioastronautics Critical Path Roadmap Risk Management Process

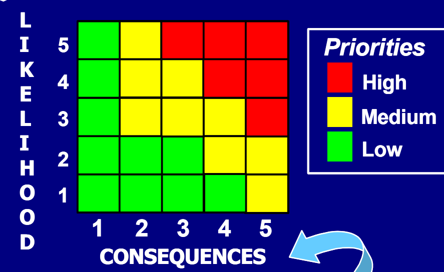


(1) Identify the critical risks for each mission scenario

The BCPR provides the framework for the Bioastronautics risk management process. Fifty-five (55) risks (and the critical research questions/issues associated with each of the risks) were identified using previous advisory committee recommendations and the deliberation and judgment of discipline teams comprised of clinical, biomedical research, and engineering experts. These 55 risks fall into 12 disciplines and are allocated across the three functional components of Bioastronautics (space medicine and health care systems, environmental and habitability factors, and human adaptation and countermeasures). Figure 3 illustrates the overall risk management process used by the teams of experts. The components of the BCPR are baselined through a configuration control process that has the authority to review and disposition changes to the BCPR as new knowledge is gained, critical questions answered, and risks abated. (http://criticalpath.jsc.nasa.gov/)

Figure 4. Bioastronautics Risk Management Definition for Scoring Likelihood and Consequences to Illustrate Risk Priorities

Likelihood	*What is the likelihood the risk will occur?*		
	Level	Probability	. . . probability of occurrence . . .
	5	Very High	95 – 100 %
	4	High	75 – 95 %
	3	Moderate	25 – 75 %
	2	Low	5 – 25 %
	1	Very Low	0 – 5 %

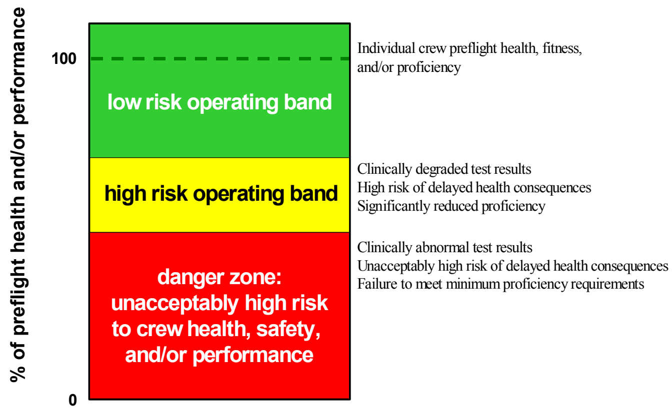


Consequence	*What is the worst-case consequence (crew or mission) if the risk occurs with the current level of mitigation?*					
	Level	1	2	3	4	5
	Crew Health, Safety, Performance	No impact to crew	Short-term minor injury, illness, incapacitation, or impairment to crewmember	Serious injury, illness, incapacitation or impairment, but not long term	Significant and long-term impairment, but not permanent	Irreversible, catastrophic impairment or death
	Mission Success	No impact to mission whatsoever, no loss of mission objectives	Relatively small impact to mission; loss limited to only a few of the mission objectives	Considerable impact and considerable loss of mission objectives	Significant mission impact; many mission objectives lost; however mission is not aborted	Significant mission impact; total loss of mission objectives; mission aborted

(2) Assess the impact of critical risks

Each risk is assigned an overall impact score based on a risk's estimated probability of occurrence and the severity of impact in terms of crew health or mission success (Risk impact = likelihood X severity). A risk's probability of occurrence and severity of impact are assessed for each mission scenario by the discipline expert teams. Figure 4 shows a schematic of the risk assessment matrix used to communicate the priority status of the risks. High-priority risks, identified as "red," are highly likely to occur, have the most significant consequences, and have the most uncertainty with regard to risk mitigation status. The overall strategy, through a focused research program and informed decision making, is to move in the direction of lowering risk priority; for example, moving red risks to yellow, yellow to green, and green to resolved/accepted. The current high-priority risks for long-duration space flight include radiation, behavior and performance, autonomous health care capabilities, and bone loss issues.

Figure 5. Acceptable Level of Risk



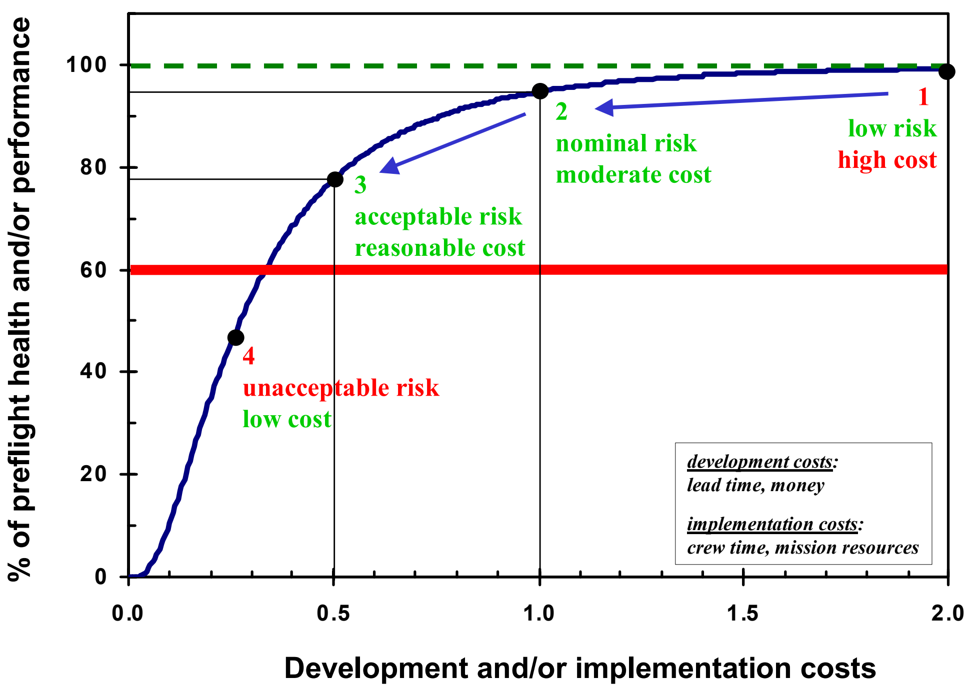
(3) Establish acceptable levels of risk

Acceptable levels of risk define the tolerance limits, or desirable operating bands, for the human subsystem (Figure 5). Teams of discipline experts define the operating bands using available data, expert opinion, and research results. The Clinical Status Evaluation (CSE) tool, based on a standard set of measures for monitoring crew health status, defines the objective evidence for tracking health status, evaluating risk management strategies, and establishing epidemiological databases for human responses to space flight. Results from the CSE will help refine the definitions of acceptable levels of risk, generate hypothesis-driven research to understand the mechanisms and develop countermeasures for the risks to humans during long-duration space flight, and monitor the efficacy of the countermeasure strategies.

(4) Apply benefit/cost analysis

Teams, comprised of discipline experts in medical operations, applied, and clinical research, establish outcomes for each of the risks. The teams perform a benefit/cost analysis as more successful risk management strategies are developed. Benefit/cost analysis allows for informed decision making and balancing of resources against potential strategies. Figure 6 demonstrates this by illustrating the benefit/cost paradigm (cost vs. acceptable risk) and the points on the abscissa indicating the most cost-effective solutions (shown as numbers "2" and "3").

Figure 6. Risk Management Benefit/Cost Ratios



Increasing Efficiency Objectives

A systematic and ongoing process will be used to determine enhanced efficiency targets for appropriate risks or functional areas. Examples of efficiency targets include the following:

- Reduce the required life support mass to orbit and beyond by a factor of 3 by 2010 through enabling knowledge and technology
- Decrease the amount of available crew time applied to the human subsystem through improvements in procedures and stowage design, communications effectiveness, systematic labeling, and revised computer interfaces so that those resources are available for other mission-related activities
- Develop advanced technologies for environmental monitoring and control systems to reduce mass and logistics and to increase crew time resources
- Increase on-orbit stay time by research to reduce radiation risk uncertainty

Returning Benefits to Earth Objectives

A systematic approach will be implemented to review, assess, and disseminate knowledge about efficacious risk management strategies that have applications for Earth-based problems. Specifically,

- All risk management strategies (including medical and environmental monitoring) and results will be reviewed and assessed annually to enable the return of important scientific and medical findings for Earth-based applications

Implementing Strategies

There are 11 strategies identified in this document that specify the overall framework for implementing the Bioastronautics risk management-based effort. Although further detailed in the Bioastronautics Tactical Plan, they are summarized as follows:

Programmatic Strategies

- Focus the existing **ground-based research program** to better understand and control the human adaptation limits that threaten the health, safety, and performance of crews during the mission and afterwards; test and prove through multiple pathways on the ground the most robust hypotheses to answer critical research questions and provide insight on potential countermeasures and health care systems
- Through an informed decision-making process, based on the BCPR, implement a focused, **outcome-driven flight research program** that delivers effective and efficient risk management solutions for understanding and controlling human limitations to living and working in the space environment, and protecting health consequences after space flight exposure
- Facilitate **integration** across all levels involved in the Bioastronautics effort including ground and flight elements; basic, applied, and clinical research; research and technology (including bioastronautics, fundamental biology and microgravity/physics); research and medicine; international and US partners; extramural and intramural discipline experts; and enterprises (Code U, M, and AM); and utilize innovative techniques such as biomedical infomatics and systems analysis towards that end.
- Implement and monitor the progress of **technology development** efforts focused on effective and efficient risk management solutions regarding medical, habitability, and human adaptation risks to crews in the space flight environment

- Foster and maintain an intellectually engaged **scholarly community** where the best minds are involved in and focused on the challenges of human space flight and are poised to provide creative and productive risk-based solutions, to help extend educational opportunities for the next generation of space clinicians, biomedical researchers, and bioengineers, and to communicate and demonstrate to the public worthwhile Earth-based contributions

Management Strategies

- Implement a risk management approach that permits **prioritization, selection, implementation, tracking, and communication** of the status and resolution of the Bioastronautics Critical Path Roadmap risks for each mission scenario
- Implement a **robust research and technology solicitation and peer review process** that utilizes the extramural and intramural scientific communities and is focused on risk management solutions at appropriate countermeasure readiness levels
- Establish an **infrastructure** (e.g., processes, personnel, and facilities) that enables program implementation and **facilitates coordination and collaboration across the multiple organizations** that share responsibility for Bioastronautics
- Implement a robust internal and external **review and vetting process** that permits timely insight and oversight by the scientific community, including the internal and external advisory committees, and ensures an appropriate level of deliberation for various elements of the Bioastronautics risk management approach
- Implement **project management practices (including information technology and communication processes)** that support **timely, accurate, and informed decision making and metrics tracking** concerning the status and resolution of critical path risks, research questions, and deliverables
- Utilize effective **partnerships with academia, industry, and international partners**, exemplified by the collaborative efforts of the risk area multidisciplinary teams, to **facilitate integrated risk management solutions** across the functional components including space medicine and health care, habitability and environmental factors, and human adaptation and countermeasures

The Bioastronautics risk management strategy is further detailed in a tactical plan that incorporates goals and objectives of Bioastronautics at the level of the three functional components. A project management approach is described; it provides specific performance metrics to track the progress of the risk management activities and thus ensures schedule, cost, and quality performance of the deliverables.

Appendices

Table A-1. Relation between Agency Objectives and Bioastronautics Goals*

Bioastronautics Goals / Agency Goals and Objectives	Reduce risks associated with human adaptation to space flight	Increase efficiencies of the human subsystem	Return benefits to Earth
Primary support enabling Goal 9: Extend the duration and boundaries of human space flight to create opportunities for exploration and discovery			
9.1 Understand and control the human health risks of space flight	X	X	
9.2 Develop knowledge and technologies to close the human life support loop and improve human performance in space	X	X	X
9.3 Create a research database that resolves fundamental low-gravity issues affecting technologies for human space travel beyond low Earth orbit (LEO)	X	X	X
9.4 Demonstrate the ability to support a permanent human presence in LEO as a stepping-stone to a human presence beyond LEO	X	X	X
9.5 Develop innovative approaches and concepts to inform future decisions concerning systems, infrastructures, and missions for the human and robotic exploration of space	X	X	X
Support for mission-driven Goal 4: Explore the fundamental principles of physics, chemistry, and biology through research in the unique natural laboratory of space			
4.1 Understand how life responds to the space environment and the role of gravity in the processes of life	X		X
Support for mission-driven Goal 7: Engage the public in shaping and sharing the experience of exploration and discovery			
7.6 Communicate to the public what biological and physical science research is taking place, why it is taking place, and how research benefits life on Earth	X		X
Support for enabling Goal 10: Enable revolutionary capabilities through new technology			
10.4 Define and implement technology investment strategies, including architecture definition, technology maturation and validation, and advanced systems development in support of future human and robotic exploration and development of space	X	X	X

* (Bioastronautics also supports indirectly Agency Goals 3, 5, 6, and 8)

Table A-2. Stakeholders, Partners, Customers/Beneficiaries, and Advisors of Bioastronautics

- Stakeholders
  - Administration (White House and OMB)
  - Congress
  - Public
  - International Partners
  - NASA
- Partners
  - Other Governmental & non-Governmental Agencies/Institutions
  - International Partners
  - Academia
  - Industry
  - NASA Program Codes/Offices
- Customers and Beneficiaries
  - Public
  - Congress
  - NASA (Crews, Flight Surgeons/Medical Operations, Engineering, Program Codes/Offices)
- Advisors
  - National Academy of Sciences Institute of Medicine *Committee on Creating a Vision for Space Medicine During Traval Beyond Earth Orbit;* and the *Committee on Aerospace Medicine and Medicine in Extreme Environments*
  - National Academy of Science Space Studies Board *Committee on Space Biology and Medicine*
  - National Research Council Space Studies Board *Committee on Advanced Technology for Support of Humans in Space*
  - NASA Advisory Committees: *Biological and Physical Research Advisory Committee* (BPRAC), *Aerospace Medicine and Occupational Health Advisory Committee* (AMOHAC)

Table A-3. Primary Organizations, Roles, and Functions for Bioastronautics

Chief Health and Medical Officer, Code AM

medical policy development & oversight (domestic & international); review and concurrence on human space flight requirements; research deliverables; medical operations implementation; compliance with applicable Federal regulations and ethical considerations

Chief Scientist, Code AS

science policy development & oversight; review & approval of science program implementation

Office of Space Flight, Code M

generation & management of health-related requirements for human space flight; oversight of space medicine health care systems; implementation of operational medicine; coordination of interagency & international partner ISS agreements concerning medical care related to space missions

Office of Biological and Physical Research, Code U

research (including advanced technology) oversight & advocacy; development of research program content with JSC; research program review and validation; coordination of interagency & ISS international partner science agreements concerning health-related research

Office of Safety and Mission Assurance, Code Q

review of risk assessment/risk management process

Johnson Space Center (JSC)

implementing center for Bioastronautics including coordination, integration, and management of biomedical, operational, and clinical research activities including the NSBRI, the telescience centers, the POIC, FCOD, flight programs, Space Architect, Glenn Research Center, and International Partners

Ames Research Center (ARC)

supporting biomedical, fundamental biology, and technology development for human space flight

Marshall Space Flight Center (MSFC)

supporting biomedical and technology development for human space flight

Kennedy Space Center (KSC)

supporting biomedical research, fundamental biology, and technology development for human space flight

Goddard Space Flight Center (GSFC)

supporting human space flight with its biomedical research consortium and technology development

Glenn Research Center (GRC)

Bioastronautics technology development

International Partners (IP)

participating through appropriate multilateral panels and processes (MMOP, MSMB, MMPB, ISLSWG, and HRMRB)

National Space Biomedical Research Institute (NSBRI)

supporting focused biomedical research for risk management purposes, including countermeasure definition and development; supporting mission critical issues for human space flight; disseminating & archiving data; performing advocacy/development of the space biomedical research community

Brookhaven National Laboratories (BNL) of the Department of Energy

supporting focused radiobiology and radiation protection research by operating and maintaining the only facility in the United States that can simulate the full range of the space radiation environment

Table A-4. The Bioastronautics Critical Path Roadmap Risks, Ranks, and Discipline Areas

ID[1]	Risk Title[2]	Rank[3]	Discipline Area[4]
1	Inability to Maintain Acceptable Atmosphere in Habitable Areas	1	Advanced Life Support
2	Inability to Provide and Recover Potable Water	2	Advanced Life Support
3	Inadequate Supplies (including maintenance, emergency provisions, and edible food)	2	Advanced Life Support
4	Inability to Maintain Thermal Balance in Habitable Areas	3	Advanced Life Support
5	Inability to Adequately Process Solid Wastes	3	Advanced Life Support
6	Inadequate Stowage and Disposal Facilities for Solid and Liquid Trash Generated During Mission	4	Advanced Life Support
7	Inadequate Nutrition (Malnutrition)	1	Food & Nutrition
8	Unsafe Food Systems	2	Food & Nutrition
9	Acceleration of Age-Related Osteoporosis	1	Bone Loss
10	Fracture & Impaired Fracture Healing	2	Bone Loss
11	Injury to Soft Connective Tissue, Joint Cartilage, & Intervertebral Disc Rupture w/ or w/o Neurological Complications	3	Bone Loss
12	Renal Stone Formation	4	Bone Loss
13	Occurrence of Serious Cardiac Dysrhythmias	1	Cardiovascular Alterations
14	Impaired Response to Orthostatic Stress	1	Cardiovascular Alterations
15	Diminished Cardiac Function	2	Cardiovascular Alterations
16	Manifestation of Previously Asymptomatic Cardiovascular Disease	3	Cardiovascular Alterations
17	Impaired Cardiovascular Response to Exercise Stress	4	Cardiovascular Alterations
18	Human Performance Failure Because of Poor Psychosocial Adaptation	1	Human Behavior & Performance
19	Human Performance Failure Because of Sleep and Circadian Rhythm Problems	2	Human Behavior & Performance
20	Human Performance Failure Because of Human System Interface Problems & Ineffective Habitat, Equipment, Design, Workload, or Inflight Information and Training Systems	3	Human Behavior & Performance
21	Human Performance Failure Because of Neurobehavioral Dysfunction	4	Human Behavior & Performance
22	Immunodeficiency/Infections	1	Immunology, Infection & Hematology (I, I & H)
23	Carcinogenesis Caused by Immune System Changes	1	I, I & H
24	Altered Hemodynamic and Cardiovascular Dynamics caused by Altered Blood Components	1	I, I & H
25	Altered Wound Healing	2	I, I & H
26	Altered Host-Microbial Interactions	3	I, I & H
27	Allergies and Hypersensitivity Reactions	2	I, I & H

ID[1]	Risk Title[2]	Rank[3]	Discipline Area[4]
28	Loss of Skeletal Muscle Mass, Strength, and/or Endurance	1	Muscle Alterations & Atrophy
29	Inability to Adequately Perform Tasks Due to Motor Performance, Muscle Endurance, and Disruption in Structural and Functional Properties of Soft & Hard Connective Tissues of the Axial Skeleton	1	Muscle Alterations & Atrophy
30	Inability to Sustain Muscle Performance Levels to Meet Demands of Performing Activities of Varying Intensities	2	Muscle Alterations & Atrophy
31	Propensity to Develop Muscle Injury, Connective Tissue Dysfunction, and Bone Fractures Due to Deficiencies in Motor Skill, Muscle Strength and Muscular Fatigue	3	Muscle Alterations & Atrophy
32	Impact of Deficits in Skeletal Muscle Structure and Function on Other Systems	not ranked	Muscle Alterations & Atrophy
33	Disorientation and Inability to Perform Landing, Egress, or Other Physical Tasks, Especially During/After G-Level Changes (Acute spontaneous & provoked vertigo, nystagmus, oscillopsia, poor dynamic visual acuity)	1	Neurovestibular Adaptation
34	Impaired Neuromuscular Coordination and/or Strength (Gait ataxia, postural instability)	2	Neurovestibular Adaptation
35	Impaired Cognitive &/or Physical Performance Due to Motion Sickness Symptoms or Treatments, Especially During/After G-Level Changes (Short-term memory loss, reaction time increase, drowsiness, fatigue, torpor, irritability, ketosis)	3	Neurovestibular Adaptation
36	Vestibular Contribution to Cardioregulatory Dysfunction (Postlanding orthostatic intolerance, sleep & mood changes)	4	Neurovestibular Adaptation
37	Possible Chronic Impairment of Orientation or Balance Function Due to Microgravity or Radiation (Imbalance, gait ataxia, vertigo, chronic vestibular insufficiency, poor dynamic visual acuity)	5	Neurovestibular Adaptation
38	Carcinogenesis Caused by Radiation	1	Radiation Effects
39	Late Degenerative Tissue Effects Including Non-Cancer Mortality, Cataracts, and Central Nervous System (CNS) Effects	2	Radiation Effects
40	Synergistic Effects from Exposure to Radiation, Microgravity & Other Spacecraft Environmental Factors	3	Radiation Effects
41	Early or Acute Effects from Radiation Exposure	4	Radiation Effects
42	Radiation Effects on Fertility, Sterility, and Heredity	5	Radiation Effects
43	Trauma and Acute Medical Problems	1	Clinical Capabilities
44	Toxic Exposure	2	Clinical Capabilities
45	Altered Pharmacodynamics & Adverse Drug Reactions	3	Clinical Capabilities
46	Illness and Ambulatory Health Problems	4	Clinical Capabilities
47	Prevention and Treatment of Decompression Sickness in NASA Operations	5	Clinical Capabilities
48	Difficulty of Rehabilitation Following Landing	6	Clinical Capabilities
49	Postlanding Alterations in Various Systems Resulting in	1	Multisystem (Cross-Risk)

ID[1]	Risk Title[2]	Rank[3]	Discipline Area[4]
	Severe Performance Decrements and Injuries		Alterations
50	Allergies and Hypersensitivity Reactions from Exposure to the Enclosed Spacecraft & Other Environmental Factors	3	Environmental Health
51	Inability to Maintain Acceptable Atmosphere in Habitable Areas Due to Environmental Health Contaminants	1	Environmental Health
52	Inability to Provide and Recover Potable Water Due to Environmental Health Contaminants	2	Environmental Health
53	Inadequate Nutrition (Malnutrition) Due to Inability to Provide and Maintain a Bioregenerative System	3	Advanced Life Support
54	Difficulty of Rehabilitation Following Landing Due to Nutritional Deficiencies	4	Food & Nutrition
55	Human Performance Failure Due to Nutritional Deficiencies	3	Food & Nutrition

[1] Risk Identification number: unique number assigned to each risk (1-55) used to track/identify each risk
[2] Risk: the title of each risk
[3] Rank: assigned to each risk within its discipline; a discipline may have more than one risk with the same risk ranking (risk order)
[4] Discipline area: there are 12 discipline areas in the BCPR representing the 55 risks

Acronym List

Acronym	Definition
AMOHAC	Aerospace Medicine and Occupational Health Advisory Committee
BCPR	Bioastronautics Critical Path Roadmap
BNL	Brookhaven National Laboratories
BPRAC	Biological and Physical Research Advisory Committee
CM	Countermeasures
CRL	Countermeasure Readiness Levels
CSE	Clinical Status Evaluation
EVA	Extravehicular Activity
FCOD	Flight Crew Operations Directorate
JSC	Johnson Space Center
HRMRB	Human Research Multilateral Review Board
IOM	Institute of Medicine
ISLSWG	International Space Life Sciences Working Group
MMOP	Multilateral Medical Operations Panel
MSMB	Multilateral Space Medicine Board
MMPB	Multilateral Medical Policy Board
NAS CSBM	National Academy of Sciences Committee on Space Biology and Medicine
NSBRI	National Space Biomedical Research Institute
OBPR	Office of Biological and Physical Research
OCHMO	Office of the Chief Health and Medical Officer
OSF	Office of Space Flight
POIC	Payload Operations Integration Center

Change Control Page

Point of Contact – Code AM (Dr. Mark Shepanek)

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